

Ceramic Composite Hot Gas Filter Development

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Introduction

Hot gas particulate filters are key components for the successful commercialization of advanced coal-based power-generation systems such as Pressurized Fluidized-bed Combustion (PFBC), including second-generation PFBC, and Integrated Gasification Combined Cycles (IGCC). Current generation monolithic ceramic filters are subject to catastrophic failure because they have very low resistance to crack propagation. To overcome this problem, a damage-tolerant ceramic filter element is needed.

Objectives

Westinghouse, with Techniweave as a major subcontractor, is conducting a three-phase program aimed at providing advanced candle filters for field testing in one of the two hot gas filter systems at Southern Company Service's Wilsonville PSD Facility. The Base Program (Phases I and II) objective is to develop and demonstrate the suitability of the Westinghouse/Techniweave next generation composite candle filter for use in PFBC and/or IGCC power generation systems. The Optional Task (Phase III, Task 5) objective is to fabricate, inspect and ship to Wilsonville, and other field test sites, 15 advanced candle filters for pilot scale testing.

A major objective of the base program is to develop an oxide CMC (ceramic matrix composite) candle filter that is cost competitive with prototype next generation filters. This goal is to be achieved through the use of a low cost sol-gel fabrication process and a 3D fiber architecture optimized for high volume filter manufacturing. During the Base Program, manufacturability for large scale filter production will be assessed in order to meet the needs of commercial scale power generation facilities. The results from this assessment will be implemented during the Optional Task.

Approach

This project plans to develop an advanced filter with damage tolerance, increased durability, increased resistance to crack propagation, and non-catastrophic metal-like failure characteristics through the use of:

- A 3D continuous fiber preform for reinforcement;
- Oxide materials, which are inherently stable in oxidizing environments and have been shown by Westinghouse under DOE Contract #DE-AC21-88MC25034, Thermal/Chemical Degradation of Ceramic Cross-Flow Filter Materials, to be more resistant to corrosive alkali species than nonoxides, such as SiC and Si₃N₄; and,
- Low cost sol-gel processing.

Project Description

Westinghouse and Techniweave have undertaken a three-phase program to develop an advanced ceramic composite oxide-based candle filter. Completed and reported on previously^{1,2}, Phase I, Filter Material Development and Evaluation, activities included the laboratory-scale development, characterization, and testing of a mullite matrix 3D fiber-reinforced (Nextel 550) ceramic composite filter material. This effort focused on developing the base filter material, minimizing fabrication costs and meeting filter material requirements.

Phase II, Prototype Filter Fabrication and Evaluation, activities, presented at last year's review meeting³, included additional coupon testing of Nextel 610 (polycrystalline alumina fiber) and Nextel 720 (polycrystalline alumina + mullite fiber) CMC filter materials, the development of a prototype filter, and filter qualification testing in a simulated pressurized-bed combustion environment in the Westinghouse High-Temperature High-Pressure (HTHP) filter test facility.

Currently ongoing, Phase III, Pilot-Scale Filter Manufacturing, activities have included long term thermal exposures, high pressure flow through corrosion testing, filter fabrication and testing at Karhula, and will include the manufacture of 15 full size candle filters for field testing at Wilsonville, or other sites.

A breakdown of the experimental activity for the completed Phase I, Task 3 (Tasks 1 and 2 were the NEPA Report and Test Plan, respectively); and Phase II, remainder of Task 3 and Task 4; and for the ongoing Phase III, Task 5, follows:

¹ J. E. Lane, C. J. Painter, K. C. Radford, and J-F. LeCostaouec, "3-D Woven, Mullite Matrix, Composite Filter," pp. 329-39 in *Proceedings of the Advanced Coal-Fired Power Systems '95 Review Meeting Volume I*, Edited by H. M. McDaniel, D. J. Molloy and V. K. Venkataraman. DOE/METC-95/1018, Vol. 1. DE95009732, June 1995.

² J. E. Lane, J-F. LeCostaouec, C. J. Painter, K. C. Radford, and W-F. A. Su, "3-D Oxide/Oxide Composite Filter," *Proceedings of the Advanced Coal-Fired Power Systems '96 Review Meeting*, DOE/METC-96/1037.

³ J. E. Lane and J-F. LeCostaouec, "3-D Woven Ceramic Composite Hot Gas Filter," presented at the *Advanced Coal-Based Power and Environmental Systems '97 Conference*, Pittsburgh, PA, July 1997.

Phase I

Task 3 - Development, Qualification, and Testing of Hot Gas Filter

- 3.1 - Coupon Development, Fabrication, and Testing
 - 3.1.1 - Develop 3D Fiber Architecture
 - 3.1.2 - Develop Composite Filter Material Fabrication Process
 - 3.1.3 - Fabricate and Evaluate Best Filter Material

Phase II

Task 3 - Development, Qualification, and Testing of Hot Gas Filter

- 3.1 - Coupon Development, Fabrication, and Testing
 - 3.1.3 - Fabricate and Evaluate Best Filter Material
- 3.2 - Develop and Evaluate Prototype Candle Filters
 - 3.2.1 - Weave Filter Preforms
 - 3.2.2 - Make Prototype Candle Filters and Tubes
 - 3.2.3 - Evaluate Prototype Filters

Task 4 - Manufacturing of Hot Gas Filter

- 4.1 - Filter Manufacturing Plans
- 4.2 - Filter Materials Test Plan
- 4.3 - Topical Report

Phase III

Task 5 - Production of Filters for Pilot Scale Testing

- 5.1 - Acquire Materials and Tooling
- 5.2 - Prepare Matrix Sol
- 5.3 - Fabricate Filter Preforms
- 5.4 - Make Prototype Filters
- 5.5 - QA/QC/NDE
- 5.6 - Package & Ship Filters
- 5.7 - Prepare Final Technical Report

Results

Phase I and Phase II results are briefly summarized in the following two paragraphs. Phase III results to-date are presented and discussed in the remainder of this paper.

To date, Phase I and Phase II have been completed. Phase I activities included laboratory-scale development, characterization, and testing of a mullite matrix 3D fiber-reinforced (Nextel 550) ceramic composite filter material. Nine 3D architectures were designed, preforms and CMCs made, tested and evaluated. Permeability, 4-pt bend strength, and microstructural evaluation results were used to downselect to one 3D architecture. High-temperature flow-through corrosion tests up to 400 h and thermal aging tests in static air up to 5000 h were conducted. Corrosion tests showed that Nextel 550 fiber embrittled in the presence of sodium. The evaluation of Nextel 610 (alumina) and Nextel 720 (mullite/alumina) fibers as replacement candidates for Nextel 550 were planned for Phase II. Initial composite test panels made with N610 and N720, at the end of Phase I, showed a significant increase in room temperature bend strength as compared to N550 filter material CMCs.

Phase II activities included thermal aging and corrosion tests on N610 and N720 filter CMCs specimens and the fabrication and evaluation of full-scale filters in the Westinghouse High Temperature High Pressure Filter Test Facility. Both N610 and N720 CMCs demonstrated phase stability after thermal aging for 800 and 2000 h in static air at 870°C; x-ray diffraction showed no phase changes. Both N610 and N720 CMCs successfully passed the high temperature flow through corrosion tests at 870°C for 400 h with pulsing under steam only and steam+alkali (sodium) exposure conditions. Full-scale N610 and N720 filters were successfully fabricated and tested in the Westinghouse filter test facility.

Phase III

Phase III activities have included the fabrication of full scale, 1.5 m, filters for testing in the Ahlstrom pressurized circulating fluidized-bed combustion pilot plant in Karhula, Finland; improvements to the filter preform based on the Karhula test results; and filter manufacturing activities for producing 15 filters for additional field testing. Filters have been, or will be, manufactured in Phase III using the standard filter fabrication process, Fig. 1, which incorporates low cost solution-based processes and environmentally acceptable water-based solutions.

At the start of Phase III, four 1.5 m Nextel 720 reinforced filters were manufactured and shipped to Karhula for testing. Two filters were installed in the filter vessel; the remaining two filters were set aside for baseline properties testing. During the first 35 h of testing, these two filters developed pin hole leaks, Fig. 2, and were removed from the filter vessel. The pin-holing was related to the filter construction method, which used 2-D fabric wrapped around a mandrel with fibers stapled through-the-thickness to provide through-thickness strength. These fiber staples were blown out during backpulsing in the Karhula filter vessel and resulted in pin hole ash leaks. However, filter integrity was maintained and the flange and endcap performed successfully during this test, Fig. 3.

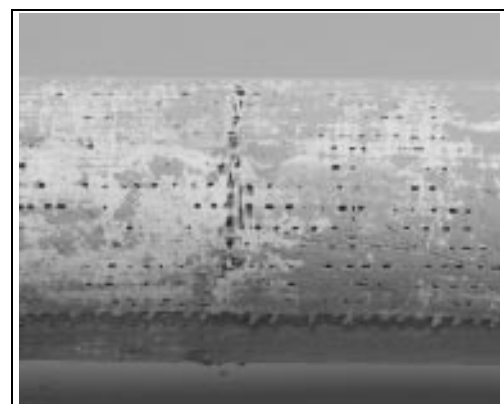
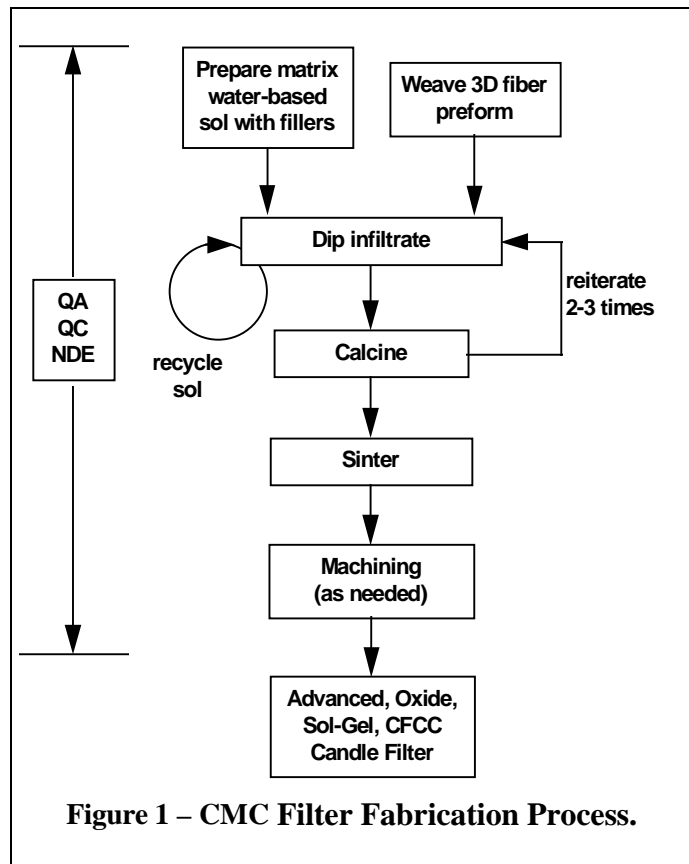
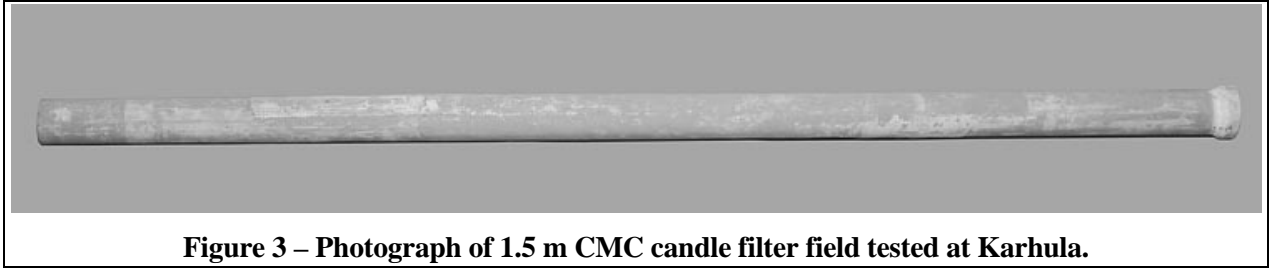


Figure 2 -- Photograph showing the pinholes which developed in the filters field tested at Karhula.



This field test at Karhula was extremely useful in identifying a filter preform construction deficiency which was not observed in the filter qualification testing at Westinghouse. Based on the field test results the staples were eliminated and an improved lower cost filter preform construction has been developed using a true 3D reinforced angle interlock architecture, Fig. 4.

This 3D architecture will provide increased toughness, strength and filter integrity. The preform fabrication uses a multi-axial braider, Fig. 5, to form in one pass a fully integral seamless candle filter preform, from flange-to-endcap. This preform fabrication approach reduces the number of fabrication steps, lowers the cost, and automates the preform process.

Future Activities

Future, Phase III, activities consist of manufacturing 15 full size candle filters for field testing at Wilsonville, or other sites.

Acknowledgments

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